LBNL LARP Dipole R&D

LARP Collaboration Meeting

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“Dipole first” IR design

Potential advantages:

- reduced number of long-range beam-beam collisions
- beam on axis & local field error correction in the IR quads

D1 Dipole requirements:

- need to separate *and* accommodate both beams: 15 T, 120 mm bore
- need to withstand large power deposition from secondaries

Magnet R&D issues:

- Operating field, forces and stresses are “beyond the state of the art”
- Mitigation of the radiation load → split coils have been suggested

LARP Dipole R&D at LBNL

Significant overlap between LARP dipole R&D & LBNL base program

For best results, need to address the following points:

- which aspects of the LARP dipole R&D are covered by the base program
- how to leverage on the base program to get early feedback for LARP
- how to effectively expand the base program toward LARP-specific R&D

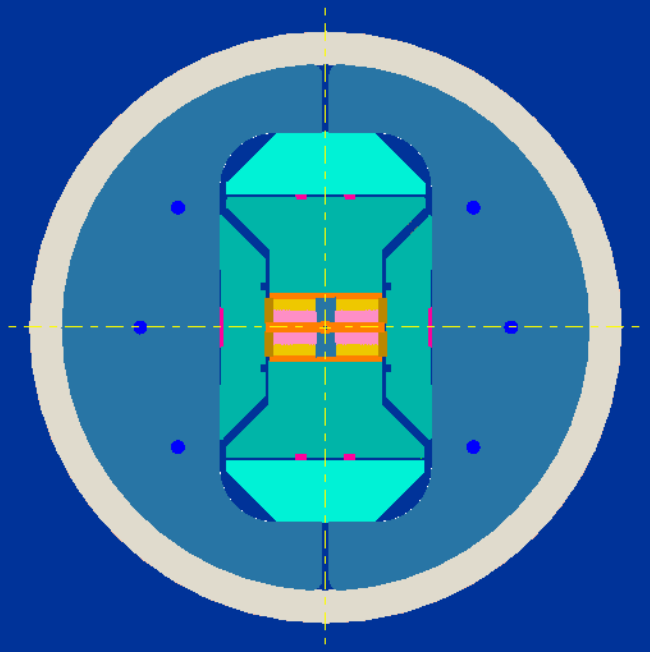
Present R&D work relevant to the LARP dipole development:

- HD: block-coils aiming at the highest possible fields (this talk)
- SM: subscale coils for technology development (S. Caspi talk)

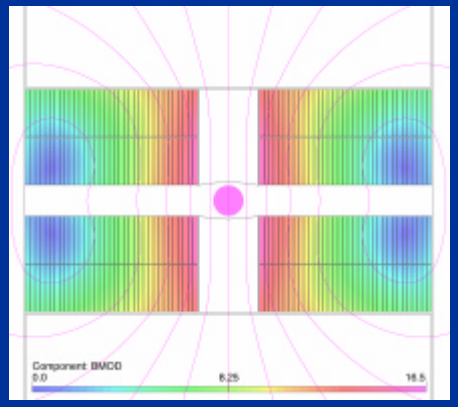
HD Series

Design Features:

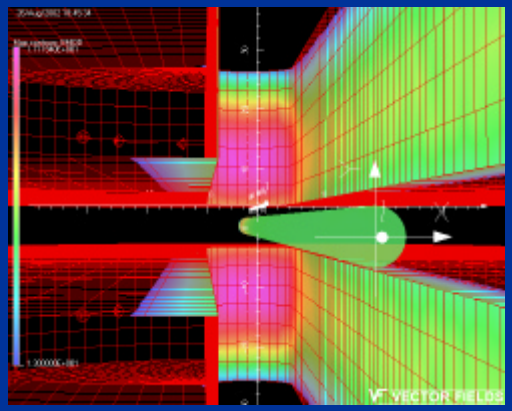
- Block-coil supported by yoke and shell
- Simple and cost-effective configuration
- Flat cables, double pancake coils
- Separation of high field/high stress points
- Bladder & key assembly
- Dipole field 15-18 T



Magnet cross-section



Coil cross-section

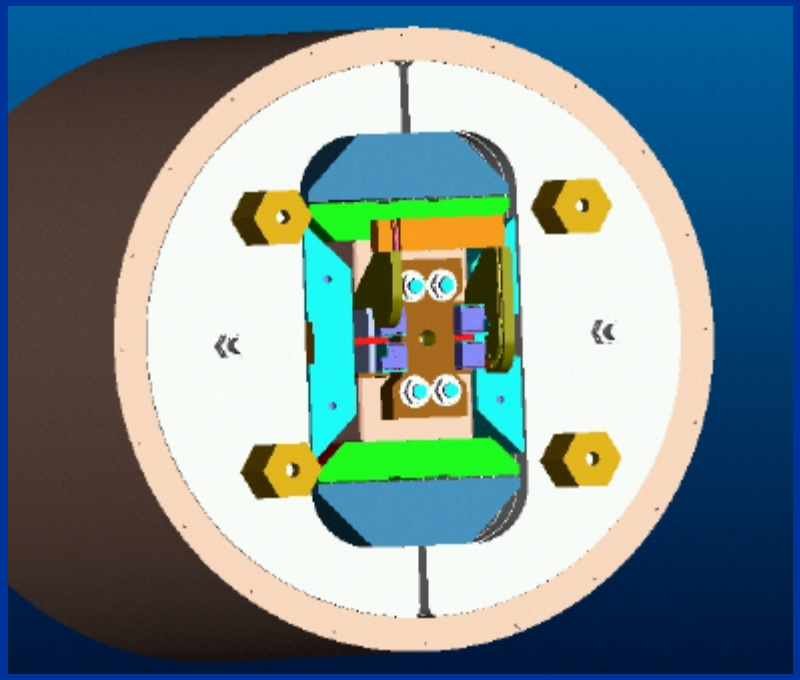


End field

First Step: HD1 Dipole

Goal (and challenge):

At one time, new coil configuration and new field record: 15+ T



SHORT SAMPLE PARAMETERS

Parameter	Unit	HD1	RD3B
$B_0^{(ss)}$	T	16.4	14.5
$I^{(ss)}$	kA	10.5	10.8
B_{max}	T	15.8	14.8
$J_{cu}^{(ss)}$	kA/mm^2	1.2-1.4	1.1/1.5

ENERGY and FORCES

Parameter	Unit	HD1	RD3B
Stored Energy	MJ/m	0.62	1.2
Inductance	MH/m	11	21
F_x (quadrant, 1ap)	MN/m	4.1	3.7
F_y (quadrant, 1ap)	MN/m	-1.3	-2.3
Max. coil stress	MPa	150	120

HD1 Coil Design & Fabrication

- Two flat double pancakes (34+35 turns)
- OST 0.8 mm wire, 3 kA/mm^2 @ 12 T, 4.2 K
- 36-strand cable, 16 mm x 1.54 mm (bare)
- Glass sleeve insulation (~100 μm thickness)

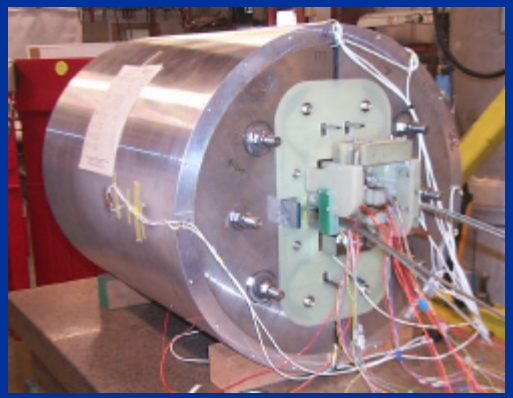
- Winding radius 10 mm (requires W&R)
- No conductor at the midplane
- Coil aperture 20x10 mm

- Magnetic pole for high field/stress
- SM-like features (horseshoe, splices)
- High Field layer transition
- End spacer for field reduction
- 70% heater coverage, both sides

HD1 Mechanical Support & Assembly

Design Features:

- RD3 shell & yoke
- Bladder & key assembly
- Horizontal+vertical bladders
- Four Al rods for axial support
- High load on broad cable face
- Non magnetic vertical pads in magnet ends (field reduction)



Vertical Forces in HD1

Lorentz force (1/4)

Fx = 4750 N/mm

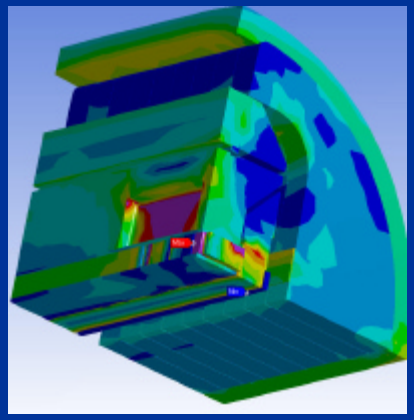
® σ_{xcoil} = 153 MPa

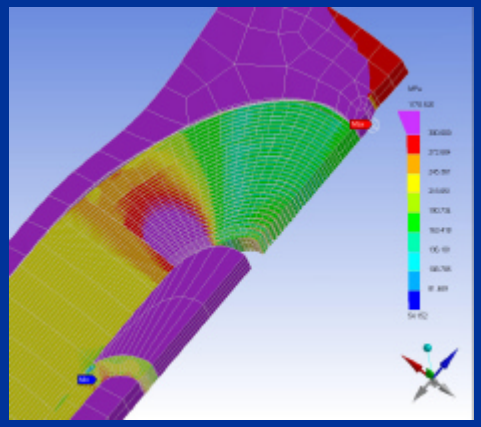
Fy = 1550 N/mm

® σ_{ycoil} = 30 MPa

HD1 Stress Analysis	Room temp.	4.3 K	Nominal field
Shell stress (MPa)	14	115	120
Coil horiz. stress (MPa)	19	148	0 - **155**
Coil vert. stress (MPa)	5	17	5 - 40
Coil max eq. stress (MPa)	20	150	**155**

- Significant vertical forces
- Vertical prestress required
- Added vertical bladders/keys
- Central spacer reacts prestress
- Role of friction?





LARP Dipole R&D with HD1

Power deposition is concentrated at the coil midplane

Strategies to mitigate this effect (Mokhov et al, PAC-03):

1. No conductor at the midplane
2. No material at the midplane

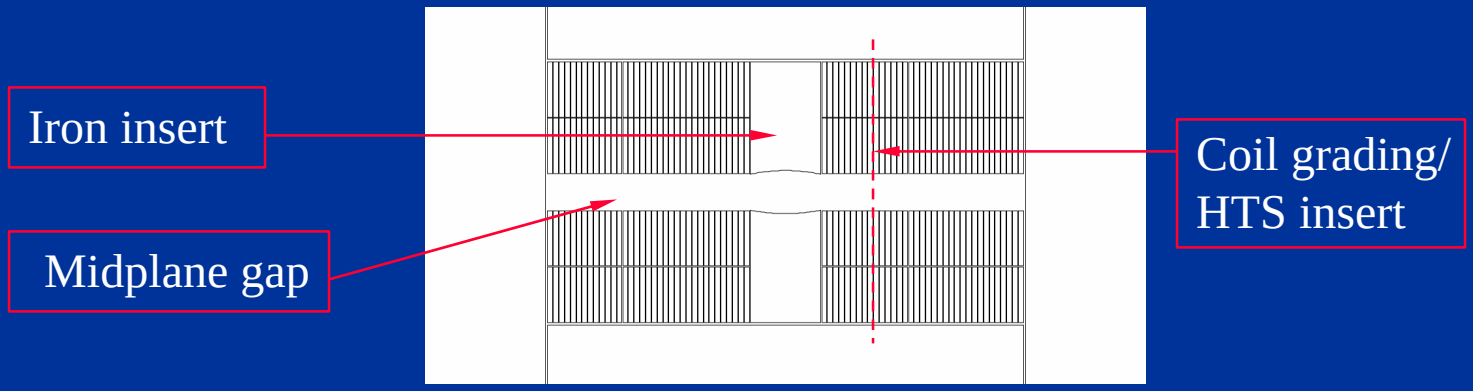
R&D issues:

- Spacer design for max support, min heating (for #1)
- Coil support against the large vertical forces (for #2)

Mechanical design studies are underway at BNL
Proposed solutions may be tested using the HD1 coils

Higher Field in the HD Series

Design features	Dipole field (T)	Iss (kA)
HD1 reference	16.2	10.5
RD3B conductor	15.3	10.0
Nb_3Sn graded coil 8 turns 1/2 dens	17.5	14.0
HTS insert 7 turns 0.8 mm 361 A @ 18 T	18.6	13.0

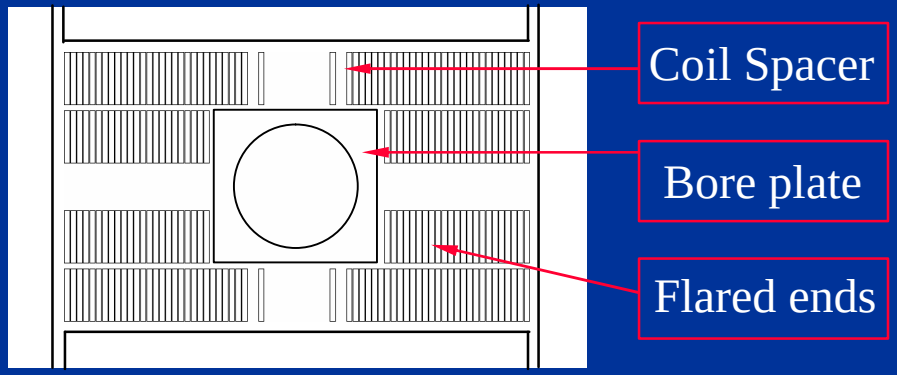


Stress analysis: Approaching 200 MPa @ 18 T

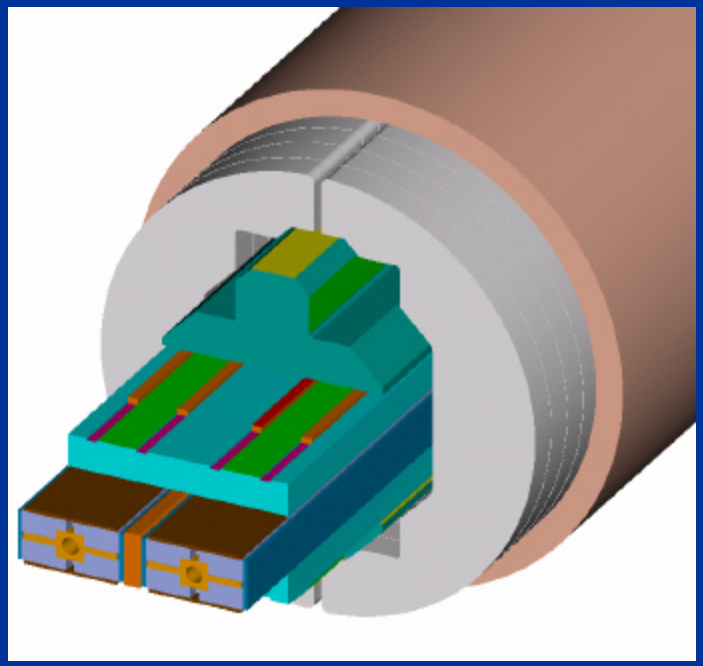
Accelerator Quality in the HD Series

Design issues:

1. Flared ends for efficiency
2. Clear bore size and support
3. Spacers & field quality



Dual bore configuration



Next steps in the HD Series

HD-2 Design Features:

- 15 T, 35 mm clear bore, 3 mm midplane spacer
- Two double pancakes, 29+35 turns, no grading
- 40 mm coil aperture, minimum bending radius 11 mm
- Geometric harmonics @ 10 mm < 1 unit (no spacers)
- Flared ends *(C. Taylor et al., IEEE MAG-19)*

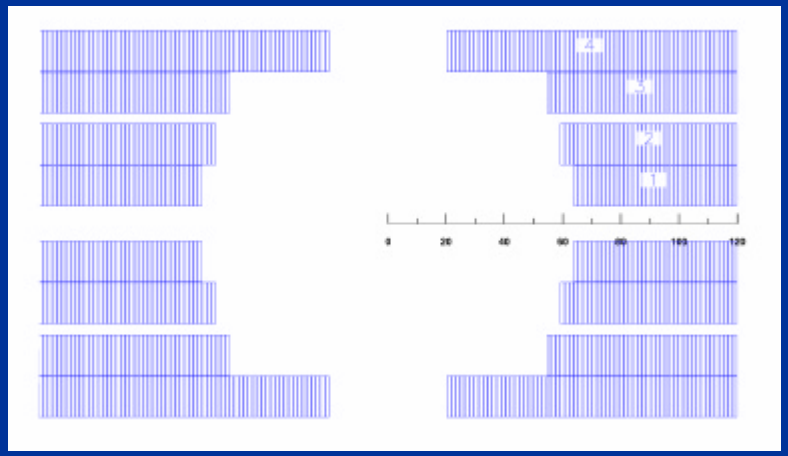
HD-3 Design Features:

- 16 T, 40-45 mm clear bore, 50 mm coil aperture
- Nested coils w/conductor grading for efficiency
- Geometric harmonics @10 mm < 0.1 units

A test of HD-1 at 1.9 K may also be considered

HD/LARP coil cross-section (vers. 1)

Two double-pancake coils in each pole, no grading/spacers, flared ends
No conductor at the midplane (± 6 mm)
Coil aperture 130 mm, short sample dipole field 14.5 T



Horizontal Lorentz stress in block 4 approaches 300 MPa at short sample

HD/LARP coil cross-section (vers. 2)

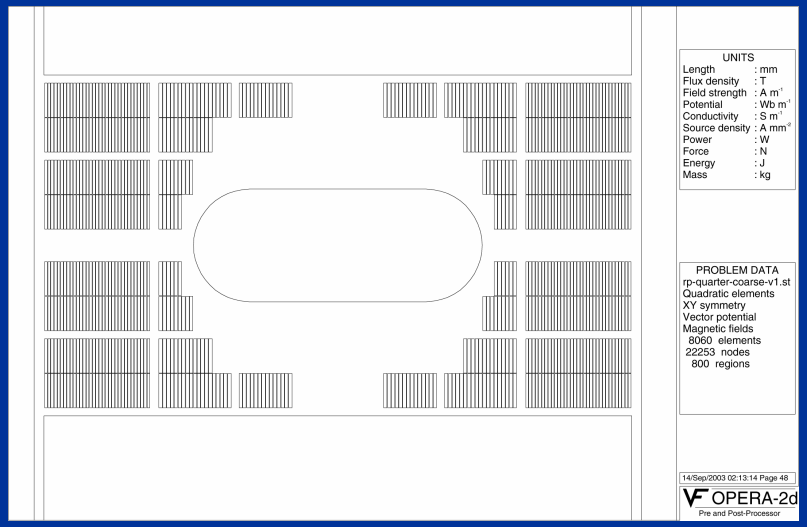
Added features:

- Intercepts to mitigate stress accumulation (Lorentz stress/block: < 150 MPa)
- Conductor grading for better efficiency (Dipole field: 15 T @ 9.5 kA)

Stored energy: LARP: 3.9 MJ/m
RD3: 1.2 MJ/m
HD-1: 0.6 MJ/m

Inductance: LARP: 90 mH/m
RD3: 21 mH/m
HD-1: 11 mH/m

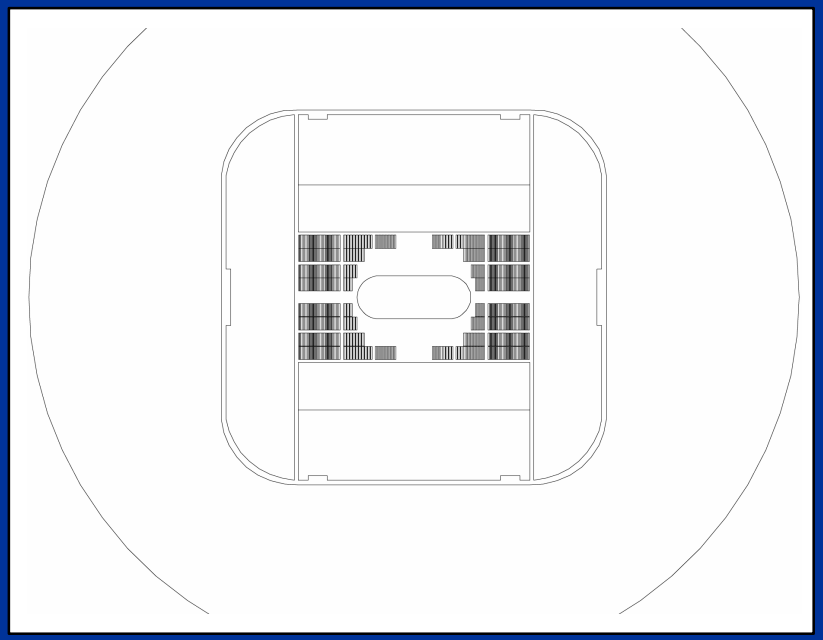
(investigate wide cable/2 layers)



Field quality: need specs - optimize at beam radius along the horizontal axis?

HD/LARP Mechanical Support

- Horizontal force at short sample:
  - LARP 20.5 MN/m
  - RD3 14.8 MN/m
  - HD1 8.4 MN/m
- Key & bladder technology can approach the required level, and avoids over-stress at assembly
- More R&D is needed
- Test of HD1/RD3c at 1.9 K?
- Bore plate: ok for the upper coil, should be analyzed for the lower coil



Summary

The LBNL base program directly relates to the LARP dipole R&D:

- HD-1 is designed to investigate stress limits at the 15-16 T level
- The HD series addresses issues relevant to the block-coil option
- The SM series investigates conductor, materials, heat-transfer etc.

Extensions are required to address LARP-specific issues:

- design features for minimal of heat deposition on the coil
- optimization of the support structure & assembly procedures
- stress intercepts to mitigate stress accumulation

Experiments using HD coils can provide early design feedback